BIOMECHANICAL DESIGN OF FOOTBALL BOOTS: EFFECT OF STUDS ON PERFORMANCE AND INJURY PREVENTION

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INTRODUCTION: The main characteristic of football (soccer) boots is that they have studs on their soles for the purpose of improving their hold on the ground, usually natural turf. This improvement of the hold aims at improving performance during displacements, and particularly during accelerations (sprints), brakings and changes in direction.

However, attaching studs not only affects performance, but frequently relates to typical football player injuries such as knee ligament injuries (Chang, 1993; Masson, 1989), and also to fractures caused by overloading the foot bones, due to problems caused by a poor distribution of plantar pressures.

In this way, performance and other aspects such as lateral stability of the foot and comfort could be affected by both the number and the distribution of the studs on the soles (Lambson *et al*., 1996; Torg *et al*., 1974).

The objective of the present work was to study the effects of different configurations (different number and location of studs) on performance, stability, plantar pressure distribution and comfort during football practice.

METHODS: Five football boot prototypes were designed and constructed, all using similar materials and construction processes. As an initial step, a first prototype was designed with 15 studs distributed on the soles according to anatomical and biomechanical criteria on foot plant areas better prepared to support the loads generated by the studs or to facilitate the application of forces for propulsion or braking during displacements. The second step was to design another three prototypes, eliminating one or more studs from the 15-stud prototype. Finally, a fifth prototype was designed copying a market-available boot with the usual distribution of studs, which, presumably, is not based on biomechanical criteria.

10 healthy subjects were selected, aged between 18 and 25, all football (soccer) players in local or provincial categories, without anomalies that could influence the normal course of the experiments or the results.

First, a study of performance in obstacle-course running was done. To do this, a course similar to that used by Brizuela *et al*. (1997) was marked on the natural ground. The circuit was delimited by means of cones and lines, and two photocell sets were used, connected to a chronometer with 0.001 second-resolution to measure the time taken by the subjects to complete the course. The subjects wore each of the five prototypes three times, trying to complete the circuit as fast as possible. The order in which the subjects wore the prototypes was random. Recovery times were set at two minutes between series and three minutes between series with different boots, in order to minimize the effects of fatigue. The times obtained were recorded for their later statistical treatment by means of an ANOVA, setting as the significance level $\alpha=0.05$, according to the classification factors: boot prototype and subject. An LSD multiple range test was also done.

To study the stability of the prototypes, a frequent movement which placed the foot at a certain eversion level was selected. In this way, a forced change of direction was chosen, similar to those made to avoid an opponent during a game, made stepping on the foot contrary to the final direction and on a natural turf ground. The subjects made 10 repetitions with each of the five prototypes at random, and changing the place of experiments every 5 repetitions so that the damaged ground wouldn't have an influence on stability. Each subject had an electrogoniometer (Penny+Gilles M180) placed on the external side of his right ankle, so that the rearfoot inversion-eversion degree could be measured at every repetition, setting the sampling frequency of the signal at 500 Hz. The signals were stored for parametrization and statistical treatment. Parametrization was done saving the maximum rearfoot inversion value at each repetition of the movement. Statistical analysis consisted of an ANOVA, setting α=0.05 as the significance level and the classification factors: boot prototype and subject. An LSD multiple range test was also done.

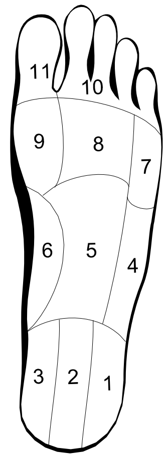

Figure 1: Delimitation of foot plant areas.

To study the plantar pressure distribution with the different prototypes, a test of running on natural ground was done, including in the right foot boot an insole instrumented with 64 piezoelectric sensors (BIOFOOT-IBV) with a sampling frequency of 100 Hz. Velocity of displacement was set to allow repeatable heel-plant running throughout the test, and all subjects wore the 5 prototypes, making 3 running series with each one. Recovery time was set at 2 minutes between repetitions to avoid the effects of fatigue. The registers of three steps from each running series were stored, obtaining a total of 9 files for each boot and subject for later treatment. Signal treatment was done by assigning certain sensors to certain areas of the foot plant (Figure 1), storing the highest pressure values for each area as statistical variables for treatment. Statistical treatment consisted of an ANOVA for the maximum pressure variable, for each area, according to the classification factors: boot prototype and subject. α=0.05 was set as the significance level, and an LSD multiple range test was also done.
To study the comfort provided by each of the prototypes, a series of football matches were played, all on the same natural ground where the subjects tested the prototypes. After playing the match, the subjects filled out a personal questionnaire which included the general opinion on the prototype (comfort level), opinions about the characteristics of the boots (hold, flexibility, etc.) and the perception of pain in body areas (discomfort or pain in certain body areas). Once the questionnaires were collected, the data were stored in a data base and some variables were later statistically treated: "general comfort", "pain in body areas" and "subjective opinion" by means of an ANOVA (Kruskal Wallis for category variables), with a significance level α=0.05. An LSD multiple range test was also done.

RESULTS AND DISCUSSION: Significant differences (p=0.004) were found between prototypes in the study of performance on an obstacle course. The results show prototype 1 (15 studs) as the one with the worst performance, followed by prototype 2 (14 studs). Prototype 4 showed the best performance, followed by prototypes 3 and 5 (all with 13 studs), although without significant differences between them. The relative difference between the best and the worst performing prototypes was of 1.3%.

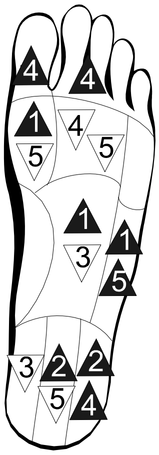

Figure 2: Numbers correspond to the prototype number. Black triangles stand for highest pressures, white triangles for pressures lower than for the other prototypes.

In the study of rearfoot lateral stability, the LSD test allowed us to classify the prototypes into three groups according the degree of rearfoot lateral stability. Prototype 2 was the most stable, followed by prototype 4. Prototypes 1, 3 and 5 were grouped as having the lowest stability or higher level of rearfoot inversion. The relative difference between the most and least stable prototypes was 14.6%.

Regarding plantar pressure distribution (figure 2), prototype 1 shows the highest pressures in areas 4, 5 and 9. Prototype 2 showed the highest pressures in areas 1 and 2. Prototype 3 showed the lowest pressures in areas 5 and 3. Prototype 4 showed the highest pressures in areas 1, 10 and 11 and the lowest in area 8. Prototype 5 showed the highest pressures in area 4 and the lowest in areas 2, 8 and 9.

In the study of comfort, the LSD test permits to classify the prototypes into three levels of general comfort. The highest comfort was provided by prototypes 4 and 5, followed by prototype 3, of intermediate comfort, and prototypes 1 and 2, less comfortable. With respect to the discomfort or pain in specific body areas, those significant ($p<0.05$) were found in the heel area for prototype 1, and under the first toe head for prototype 2. Regarding the characteristics of the prototypes, the subjects evaluated prototype 2 as having poor hold and prototypes 1 and 4 as showing poor flexibility.

Table 1: Summary of results for each prototype. Prototypes 3 and 4 have an equal number of studs, but the stud in the forefoot central area is a bit forward in prototype 4 compared to prototype 3. Prototype 5 has the classical stud distribution.

PROTOTYPE	NUMBER OF STUDS	PERFORMANCE	STABILITY	PRESSURES (DISCOMFORT)	COMFORT
1	15	Low	Low	Areas 8, 4	Low
2	14	Intermediate	High	Areas 1, 2, 8	Low
3	13	High	Low	Area 3	Intermediate
4	13	High	Intermediate	Good	High
5	13	Intermediate	Low	Areas 8, 4	High

CONCLUSIONS: Both modifications in the distribution and in the number of studs have a significant influence on performance in displacements when running, rearfoot stability, plantar pressure distribution and comfort during use.

Increasing the number of studs (to 14 or 15) decreases performance as number increases. However, differences in performance were also found in the 3 prototypes with the same number of studs, depending on their distribution. The worst performance of the three was obtained by prototype 5, with 13 studs and a conventional distribution. The prototypes whose stud distribution was designed

according to biomechanical criteria obtained the best performance, particularly prototype 4 (with the stud in the forefoot central area placed forward).
As a global analysis, the increase of pressures in the toe areas (areas 10 and 11) for prototype 4 may be caused both by an increase in performance, to favor the final stage of propulsion during running, and by the good stability this prototype presented. For the same prototype 4, the high comfort referred to by the subjects may be due to the lower pressures in the central area of the metatarsal heads (like prototype 5, which also showed high comfort) and to the absence of areas of overpressure in sensitive or delicate areas.

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